Project 32-L: Development of Cabinet-Based X-Ray Computed Tomography Methods for Studies of Microstructures and Defects in Metals

Spring Meeting

April 7th – 9th 2020

- Student: C. Gus Becker (Mines)
- Faculty: Dr. Amy Clarke (Mines)
- Industrial Mentors: Dr. Michelle Espy (LANL, E-6: Non-Destructive Testing)

Project 32-L: Development of Cabinet-Based X-Ray Computed Tomography Methods for Studies of Microstructures and Defects in Metals

- Student: C. Gus Becker (Mines)
- Advisor(s): Amy Clarke (Mines)

Project Duration

PhD: August 2017 to May 2021

- Problem: Industrial processes of metals such as casting and additive manufacturing can benefit from static/dynamic radiography, but user facilities have technique and access limitations.
- Objective: Analyze existing radiography and tomography data and establish cabinet-based x-ray capabilities at Mines for further experimentation.
- Benefit: Identify technique limitations for defect detection in AM metals and studies of solidification.

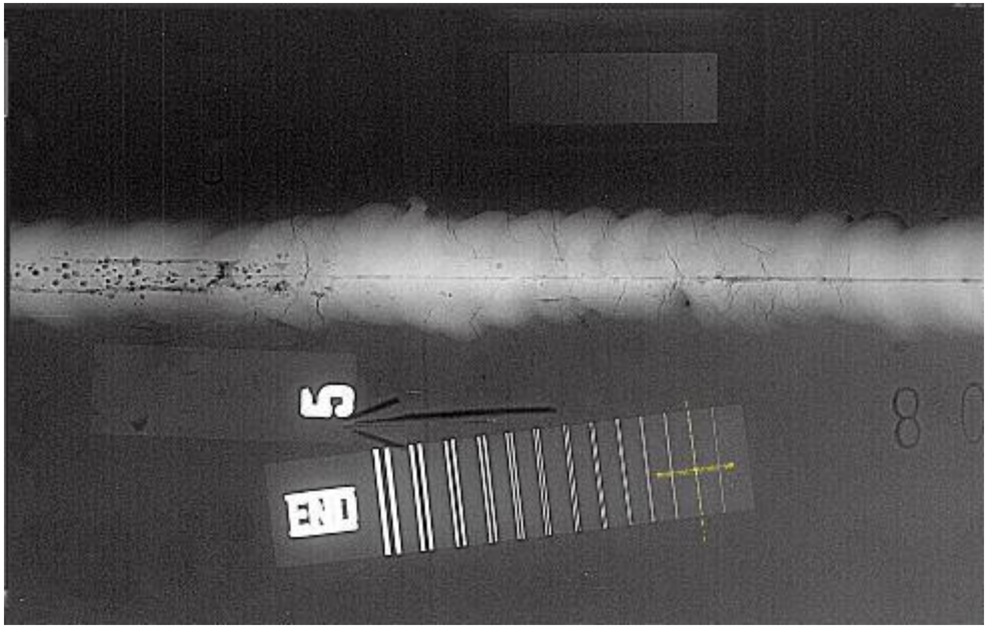
Recent Progress

- Explored new methods of automatically tracking the solid-liquid interface in AM simulator experiments from the Advanced Photon Source (APS)
- Revisited ImageJ macro to manually track the solid-liquid interface in AM simulator experiments rewrote to extract more useful data

Metrics		
Description	**% Complete**	**Status**
1. Acquisition of AM lattice structures for XCT investigation and characterization	100%	●
2. Establishment of high-energy micro-focus X-ray capabilities at Mines	80%	●
3. Development of new solid-liquid interface tracking methodology for AM Simulator experiments	100%	●
4. Development of processing routine for solid-liquid interface position data	50%	●
5. Processing of interface position data to extract velocity and evolution data	0%	●

Industrial Relevance

- Identify defects in additively manufactured (AM) builds by non-destructive imaging
  - Qualification and certification
  - Technique limitations
- Weld inspection
  - Safe and stable welds
  - Failure points, inclusions, porosity



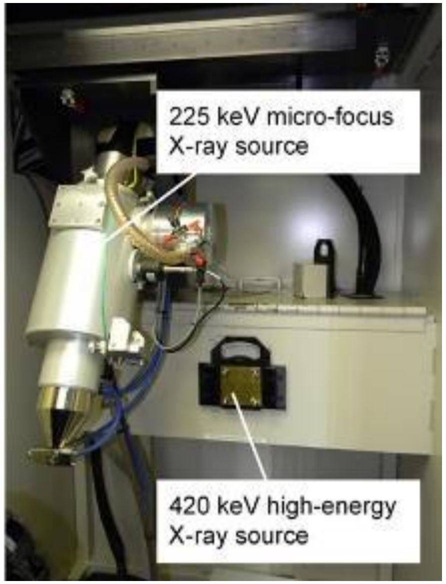
http://solutionsinimaging.com/industrial-applications/weld-inspection/

Industrial Relevance

- In-situ x-ray imaging of dynamic materials processes (e.g. casting) to inform model development

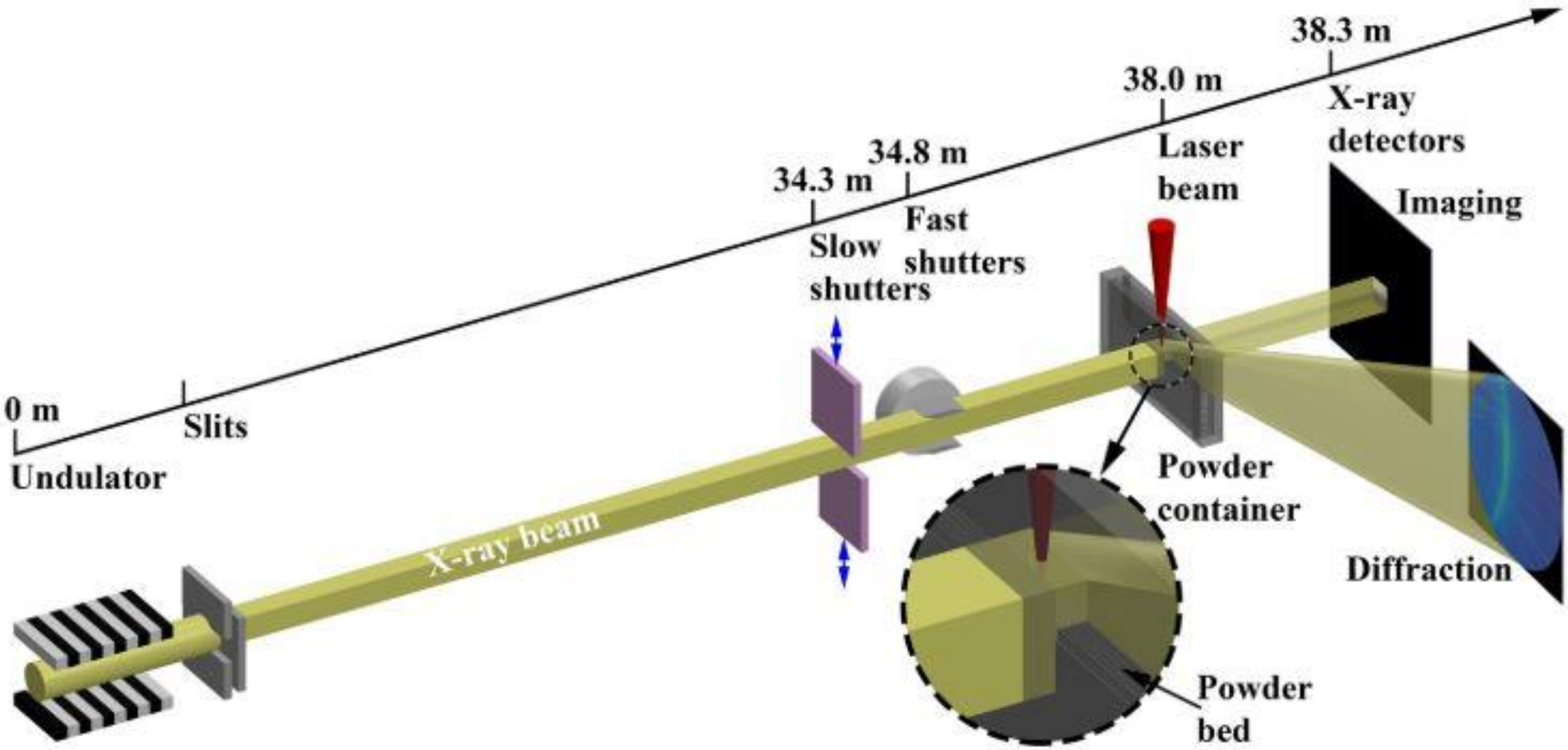
- Establishment of x-ray radiography and computed tomography (CT) cabinet at Mines
  - Characterization of materials for thesis
  - Support ongoing projects
  - Consideration of future projects from industry
  - Accommodates custom/flexible experimental platforms (solidification: casting, welding, AM, etc.; deformation: tension, compression, etc.)

Cabinet Timeline



Process Donation Internally (LANL)	Ship to White Rock, NM	Ship to Santa Clara, CA for Refurbishing	Prepare Lab Space for System	Install New Micro-Focus System	Ship to Mines and Install
Complete	Complete	Complete	Contractors on Standby	Final Stages Delayed Due to Lockdown	Delayed

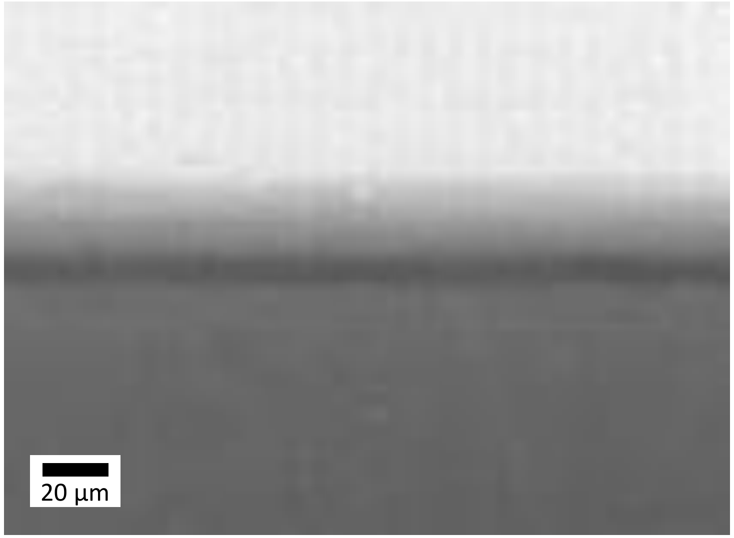
AM Simulator at the APS



C. Zhao et al., *Scientific Reports,* 7 (2017) 1-11.

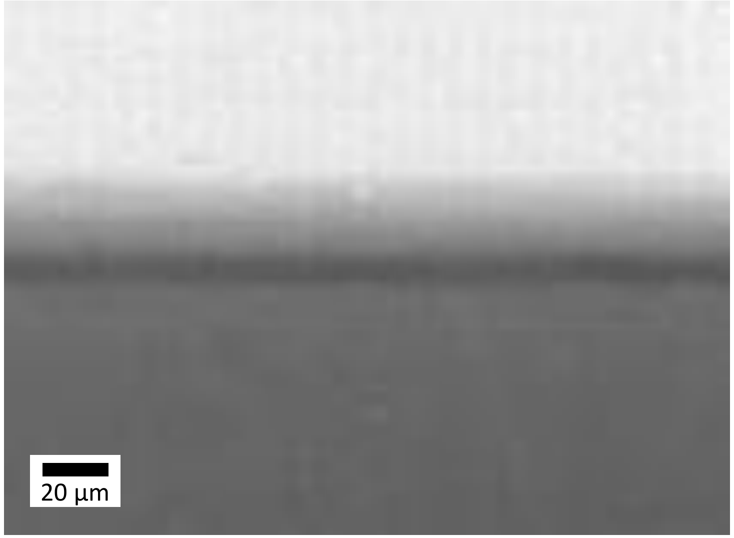
AM Simulator Example Experiment from the APS

- Ni-based alloy
- Laser power: 108 W (20% max)
- 2 ms dwell time

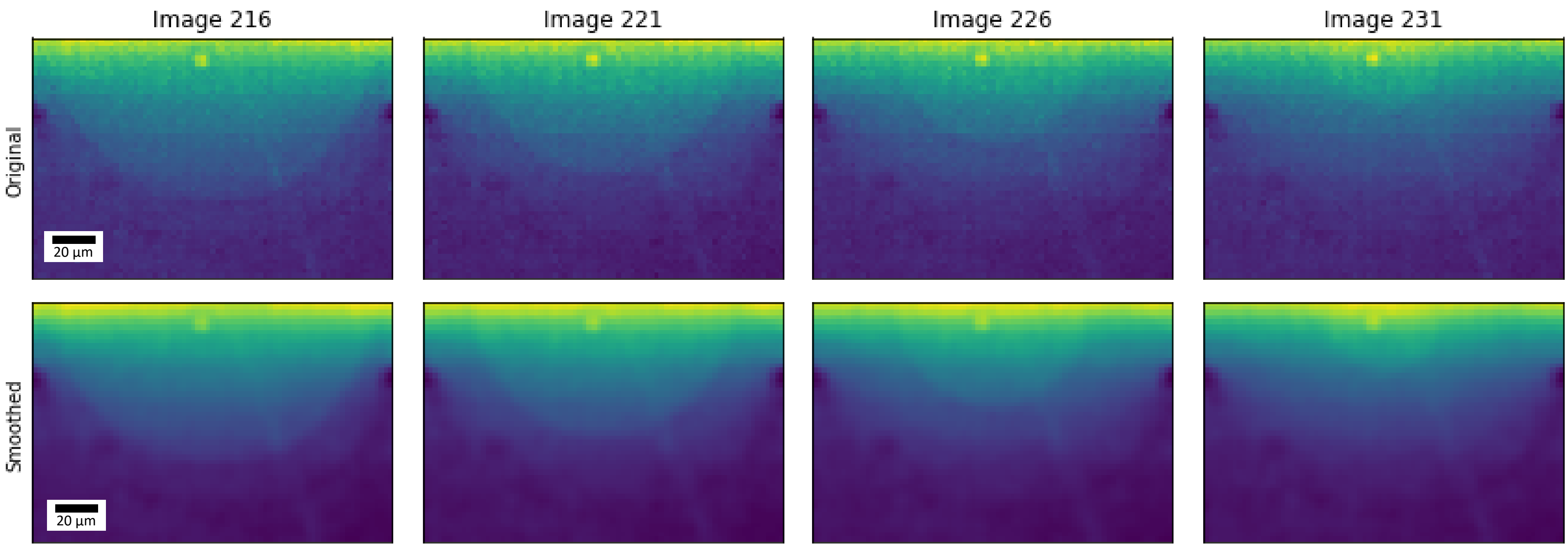


AM Simulator Example Experiment from the APS

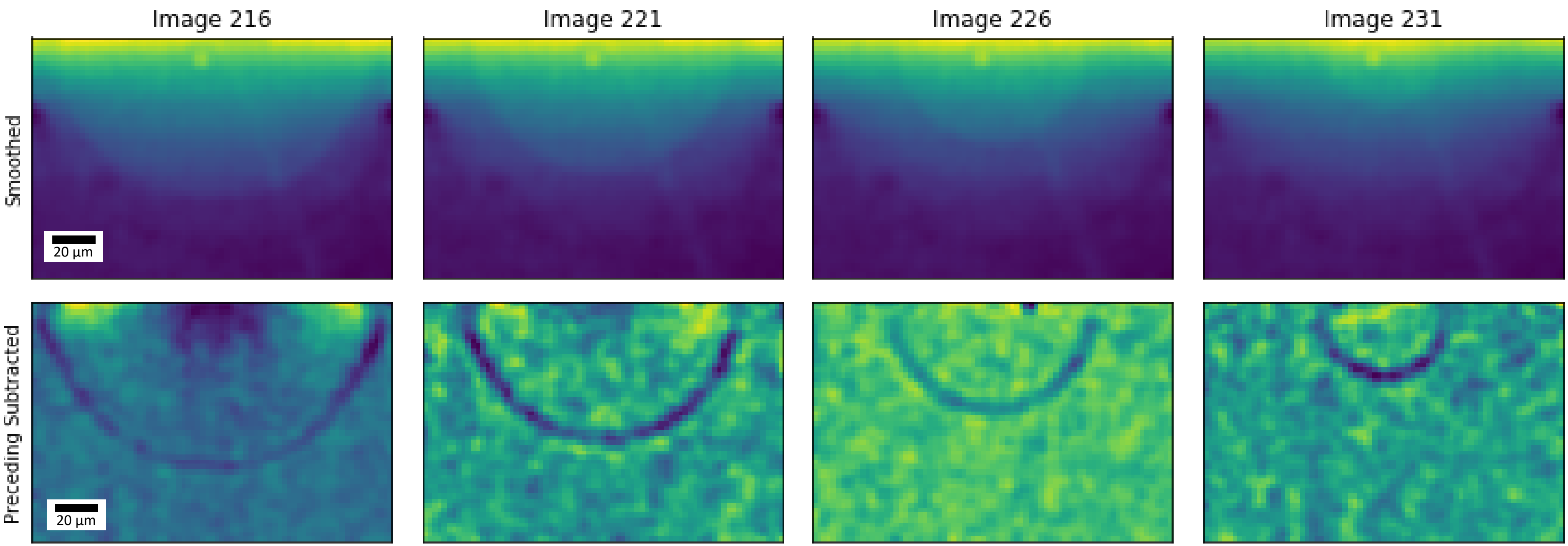
- Ni-based alloy
- Laser power: 108 W (20% max)
- 2 ms dwell time
- Importance of automation
  - Reproducubility
  - Standardization across collaborators (e.g. UCSB)
  - Reduce bias when measuring



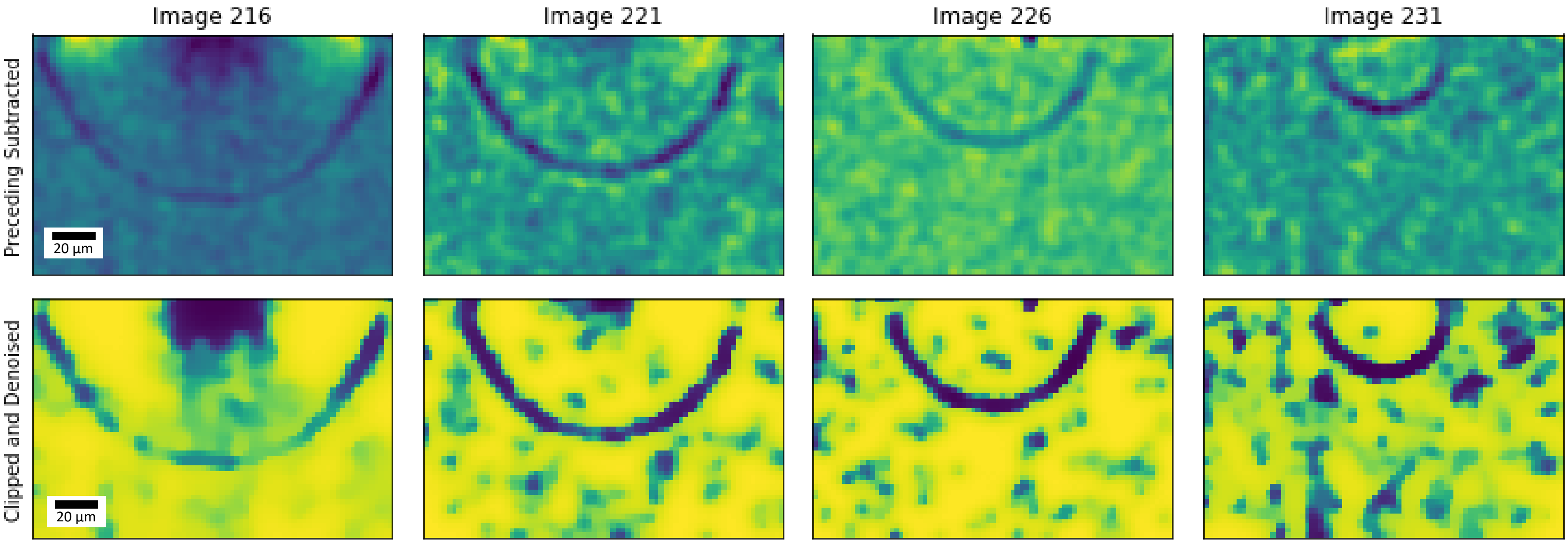
Tracking Solid-Liquid Interface



Subtract Preceding Image



Replace Top and Bottom 5% Intensities



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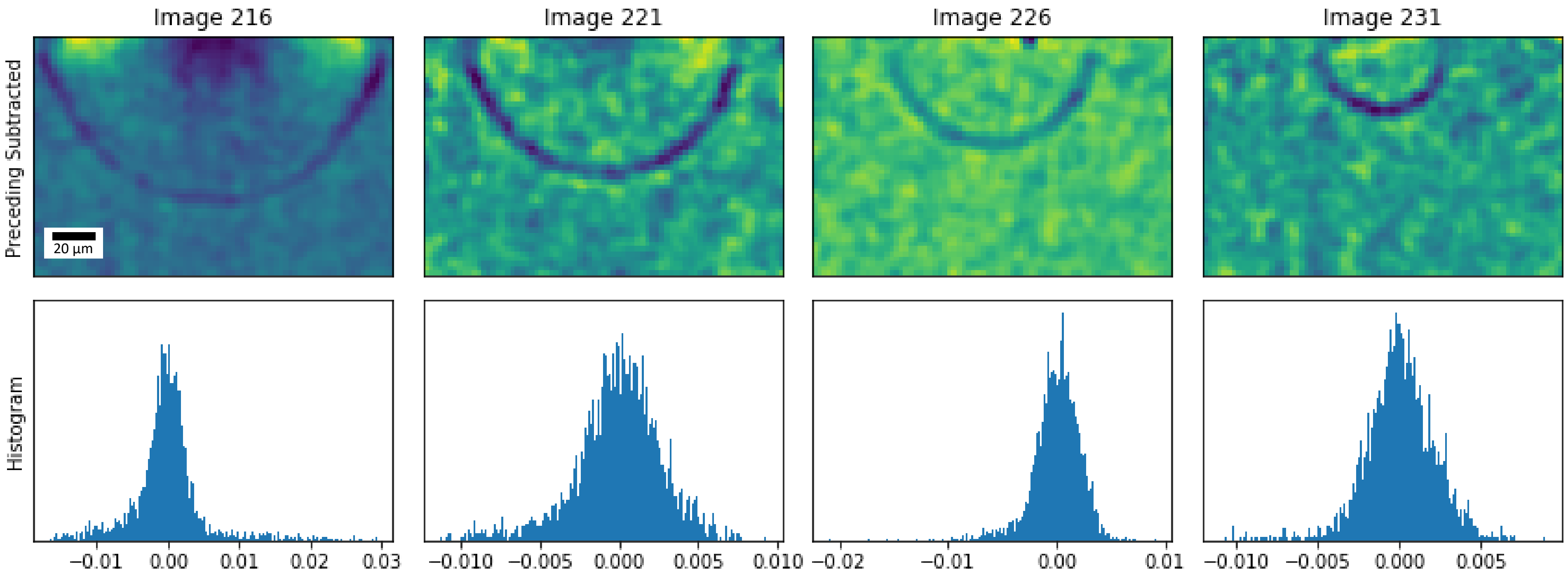

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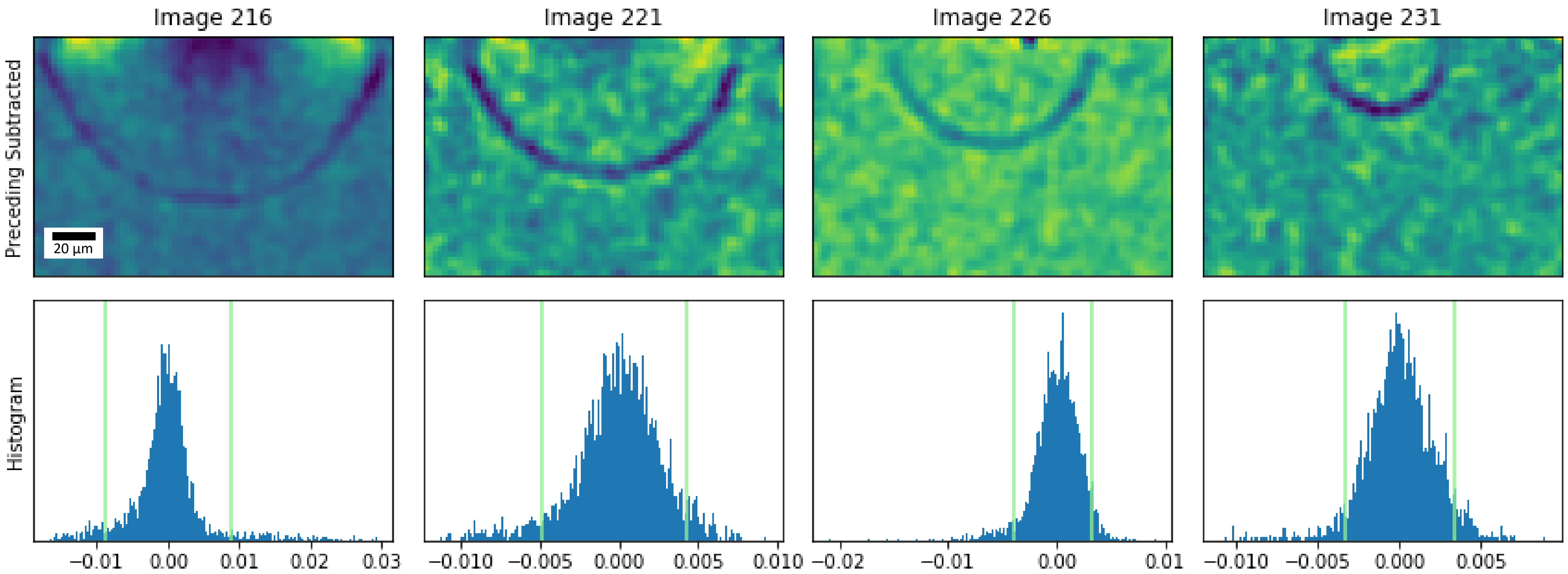

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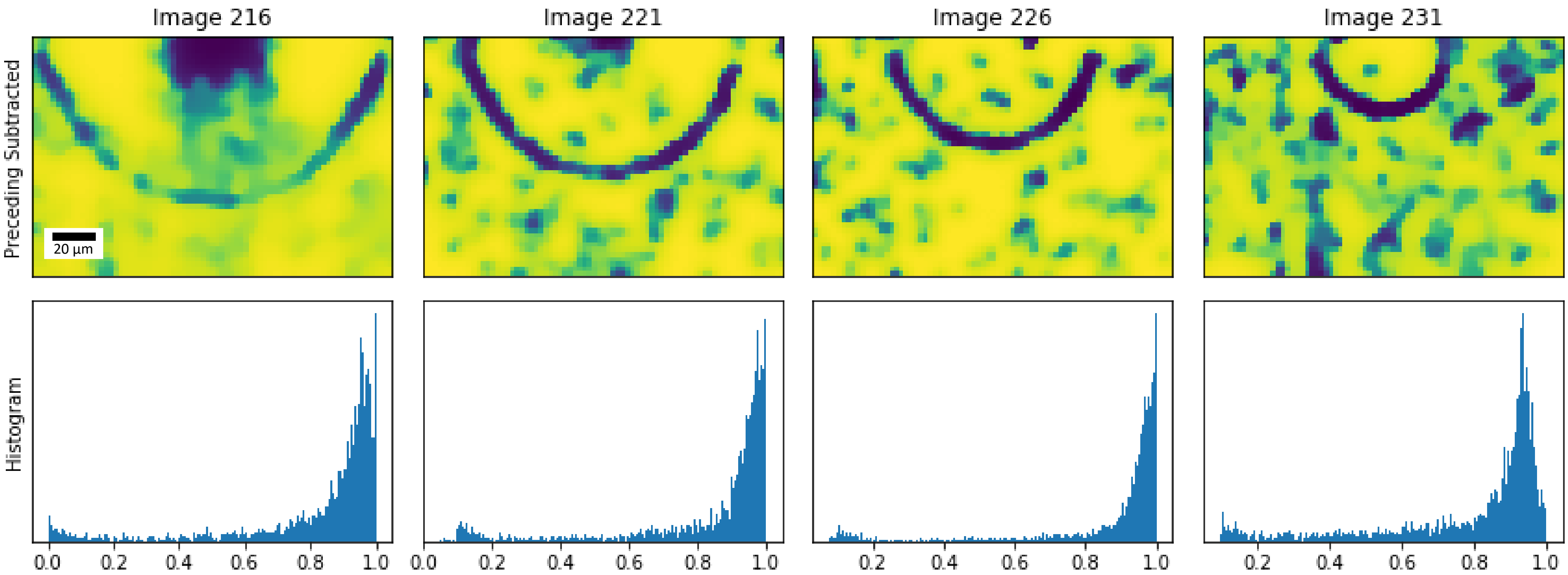

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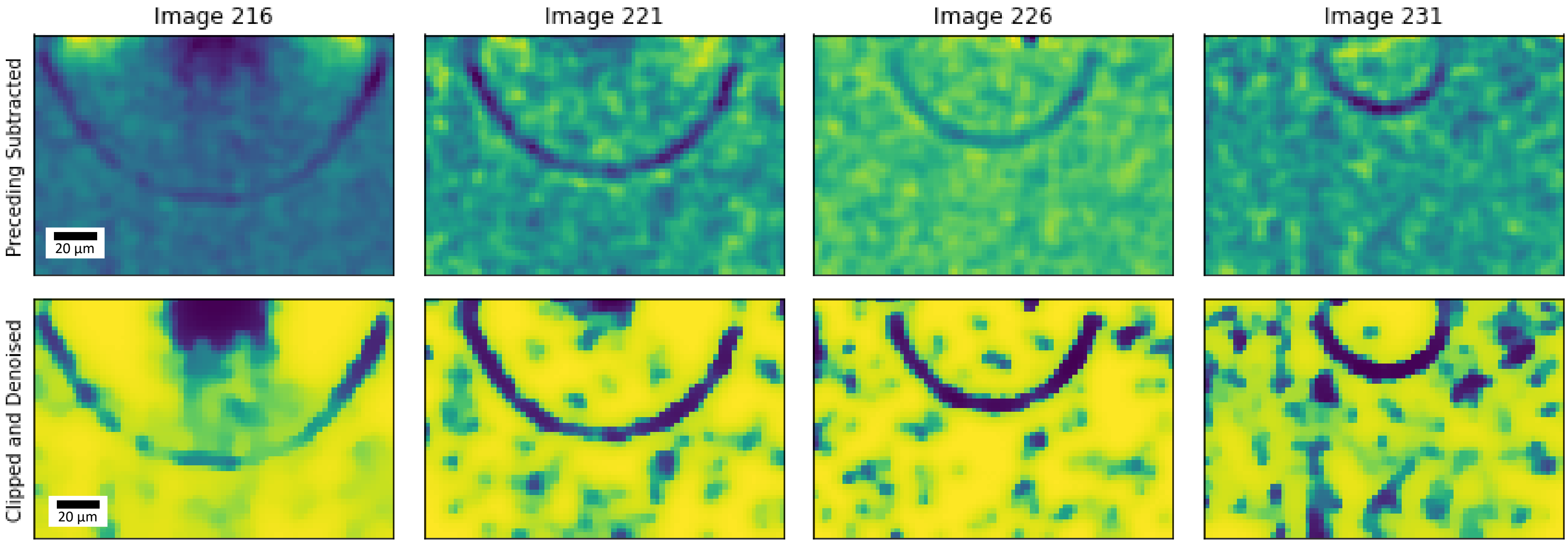
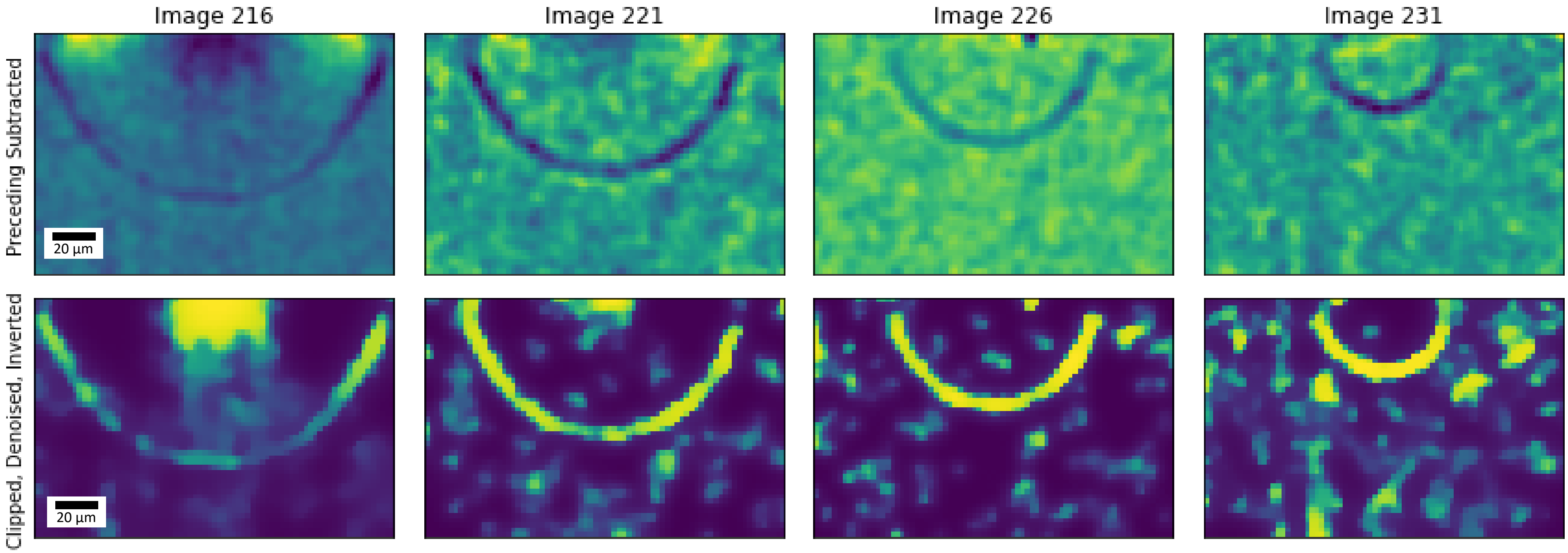
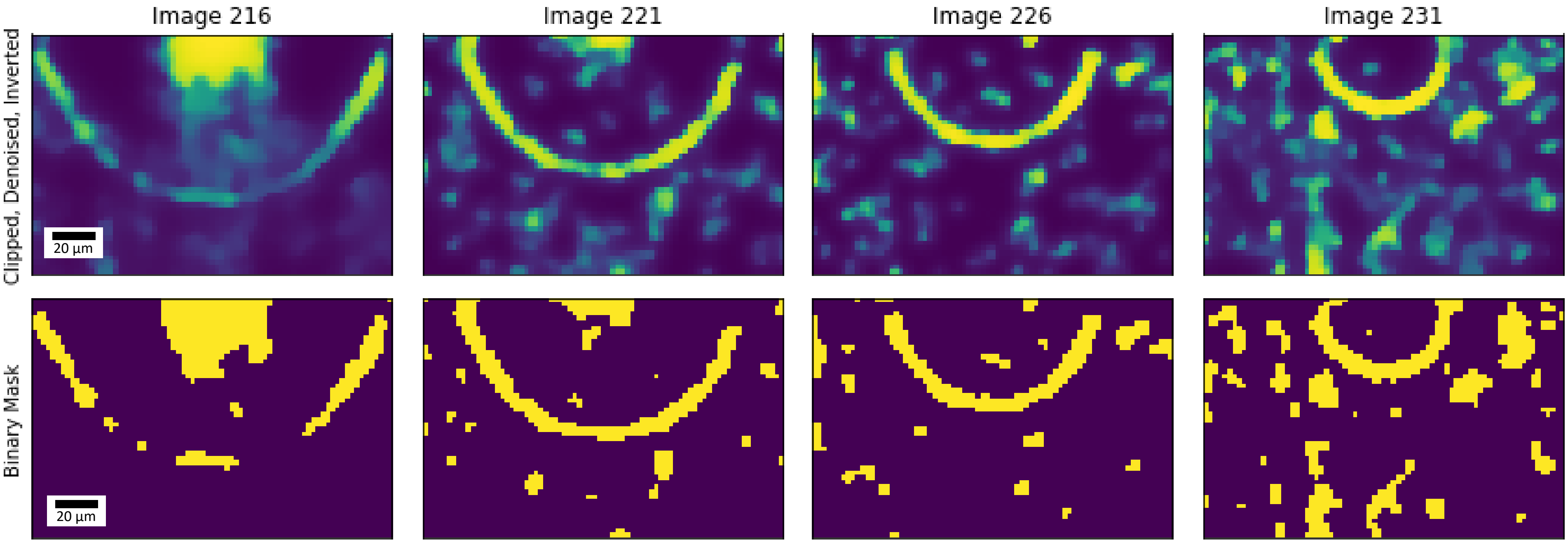


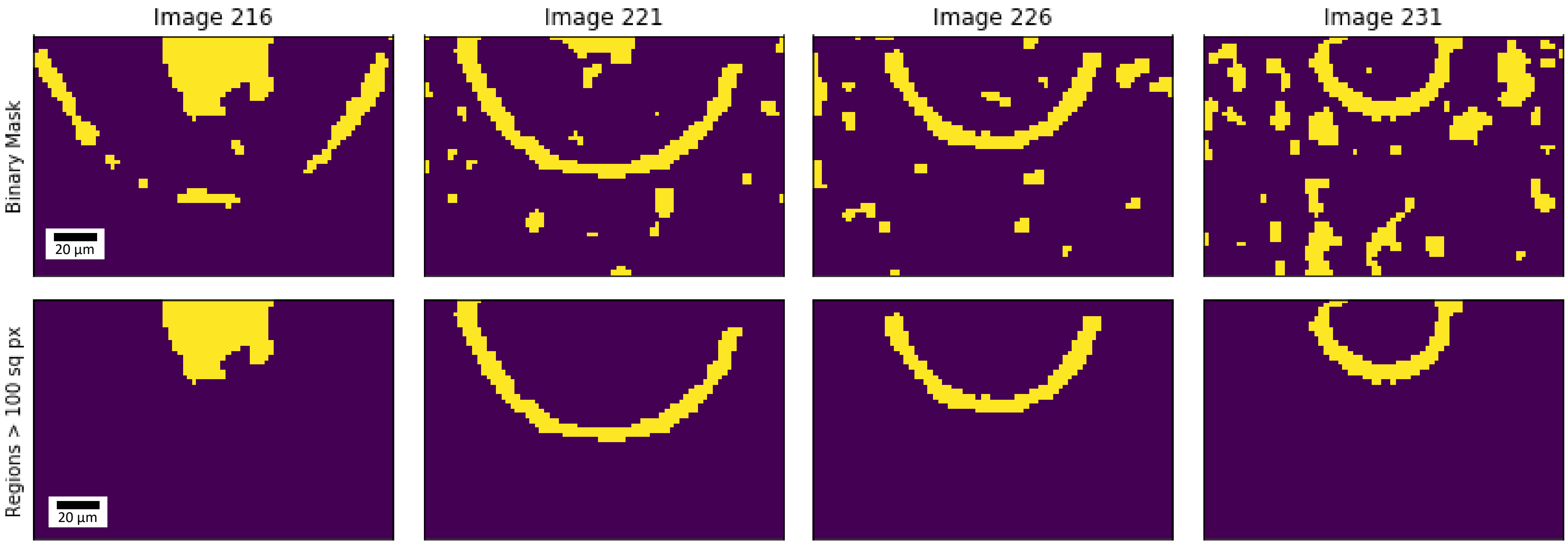
Invert for Clarity



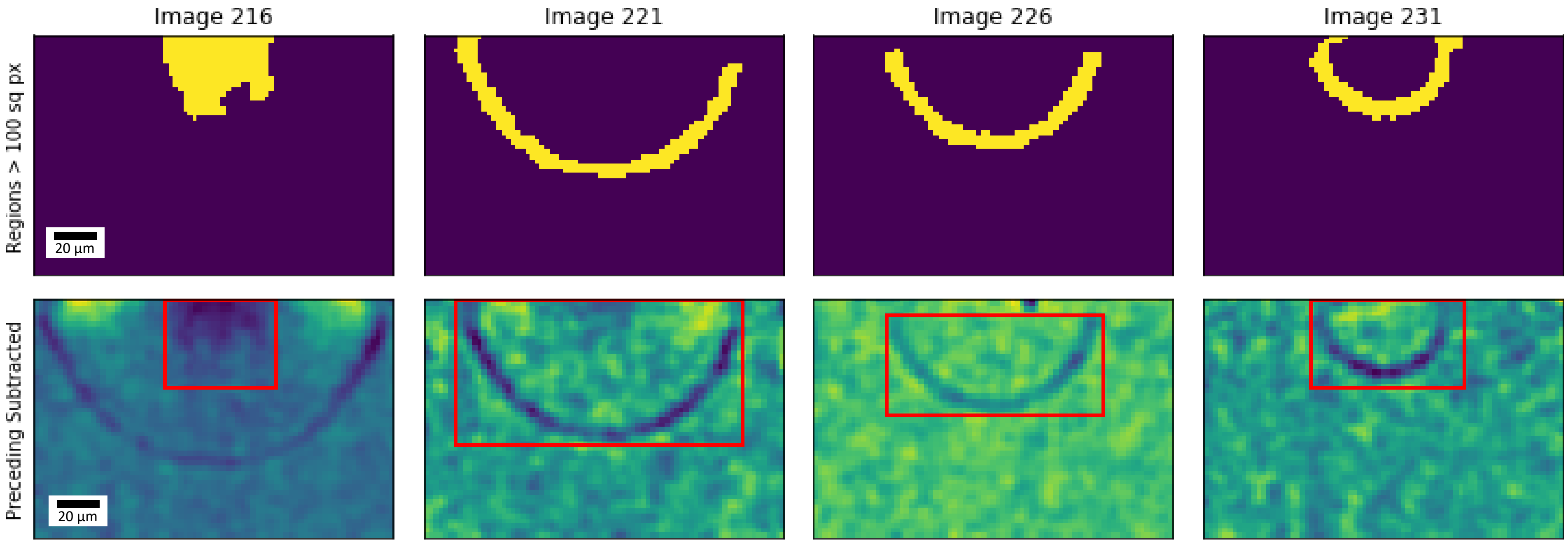
Create a Binary Image



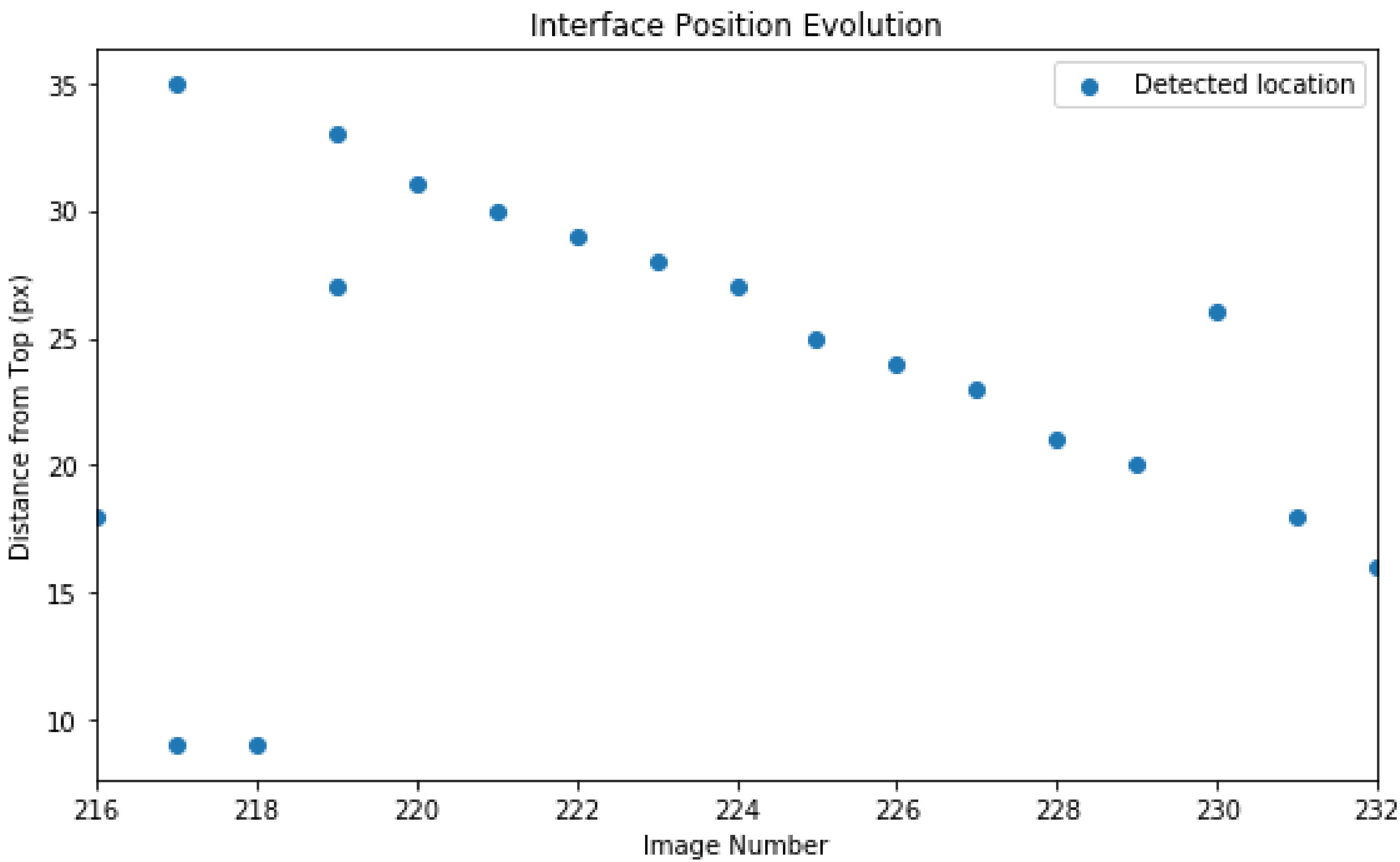
Remove Smallest Regions



Create Bounding Box



Plotting Interface Position



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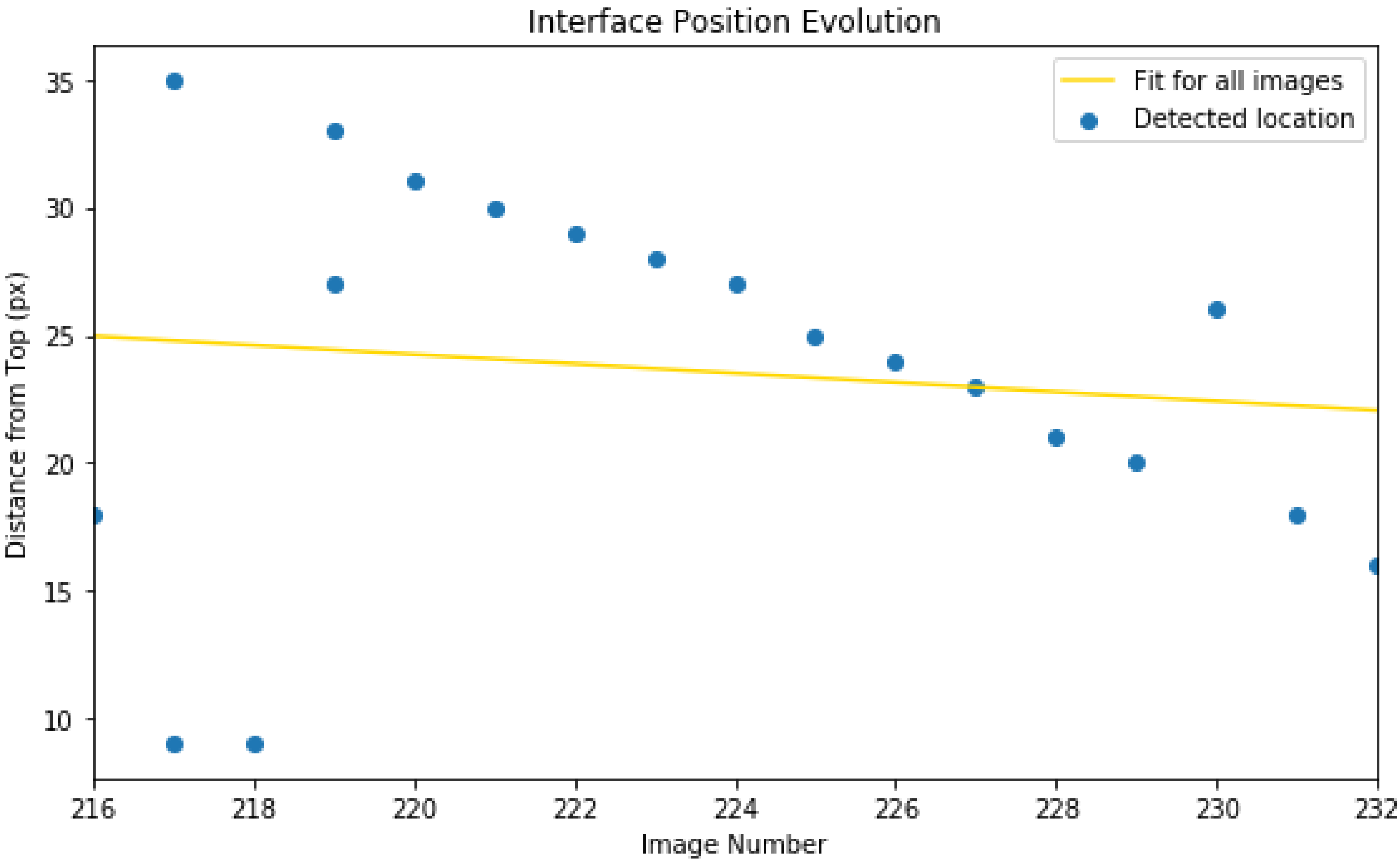

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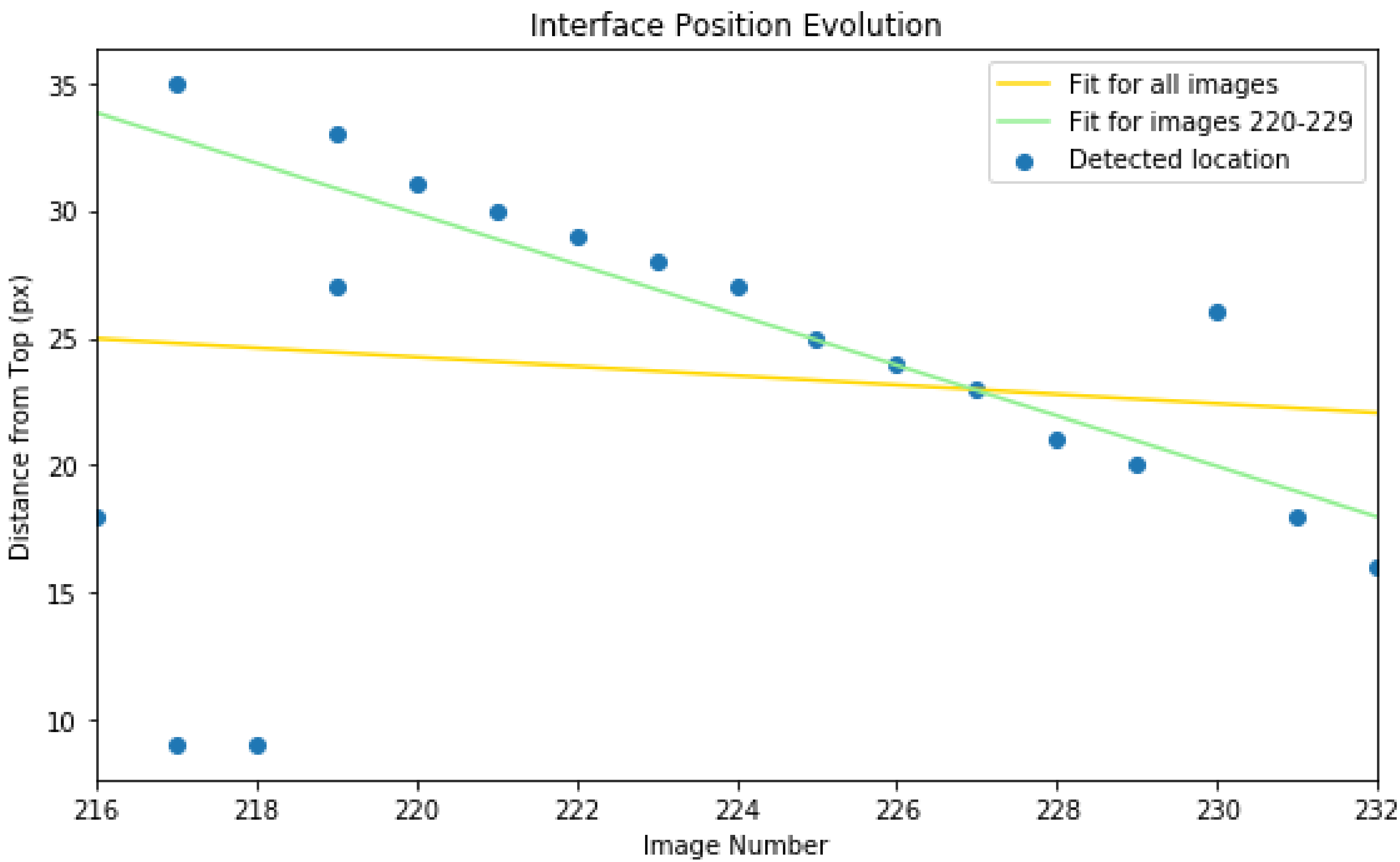
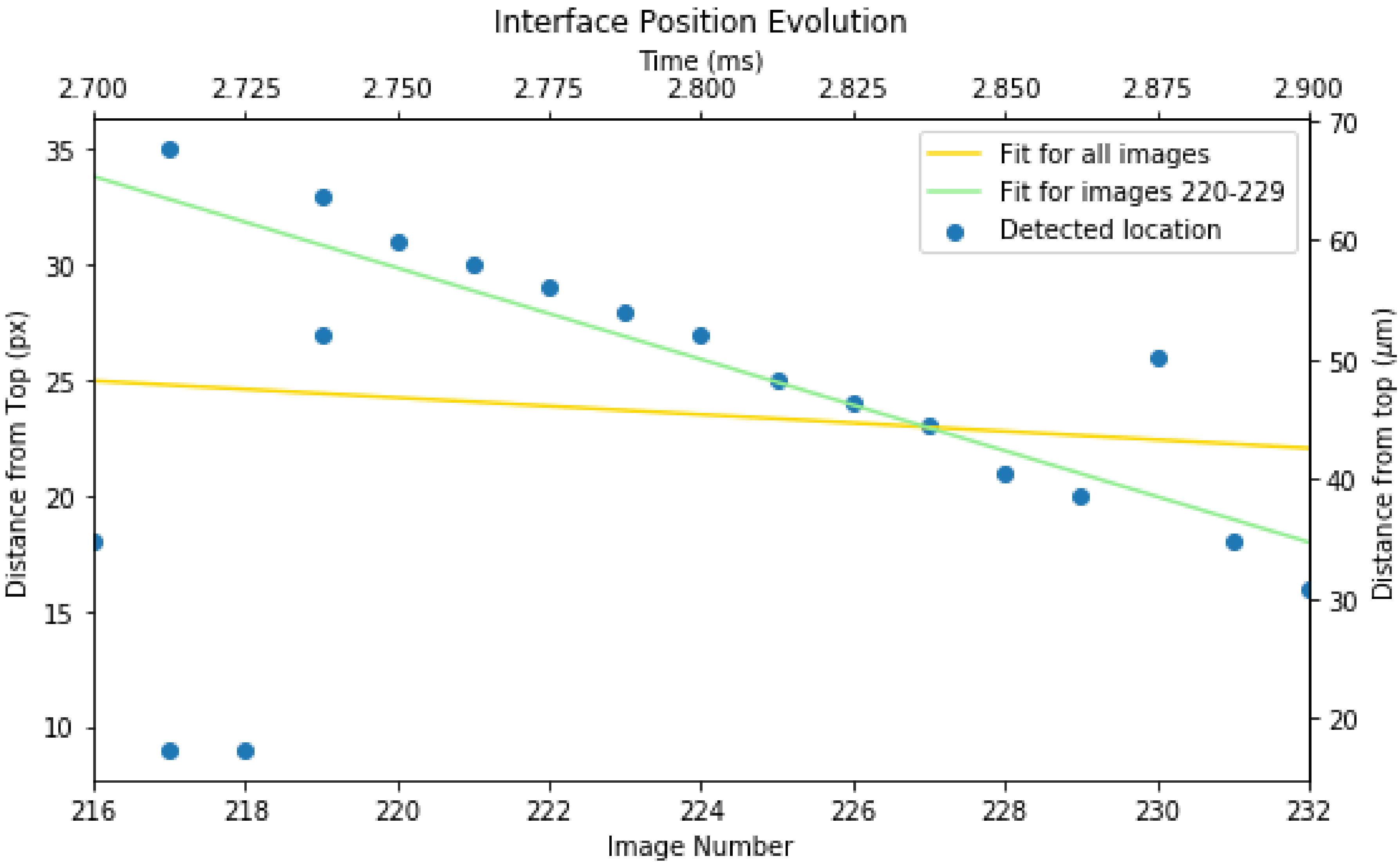
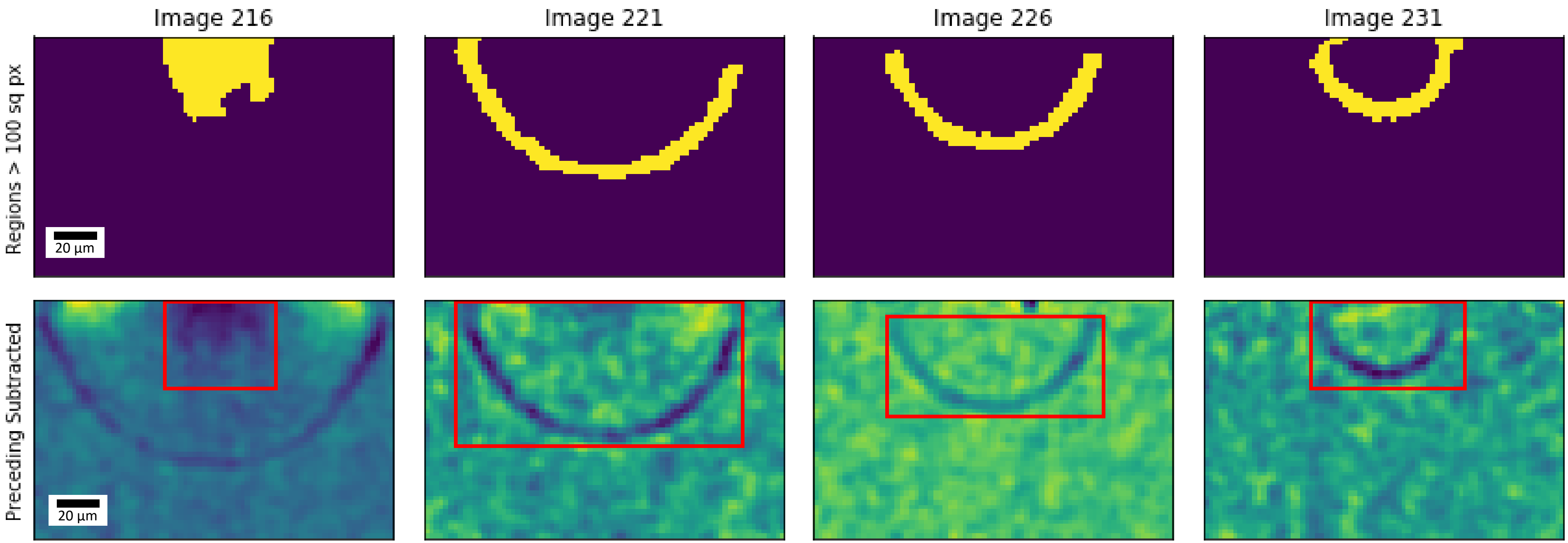


Plotting Interface Position



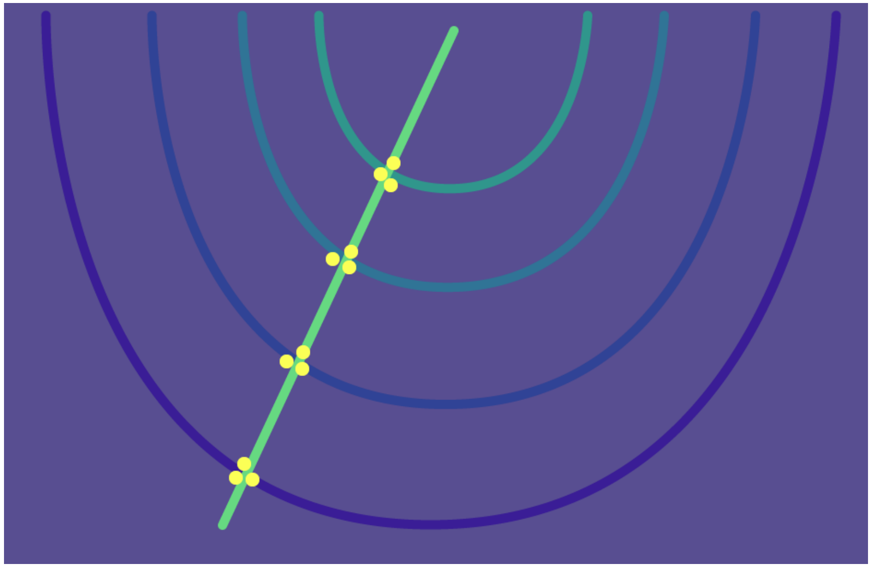
Create Bounding Box



Center Proprietary – Terms of CANFSA Membership Agreement Apply

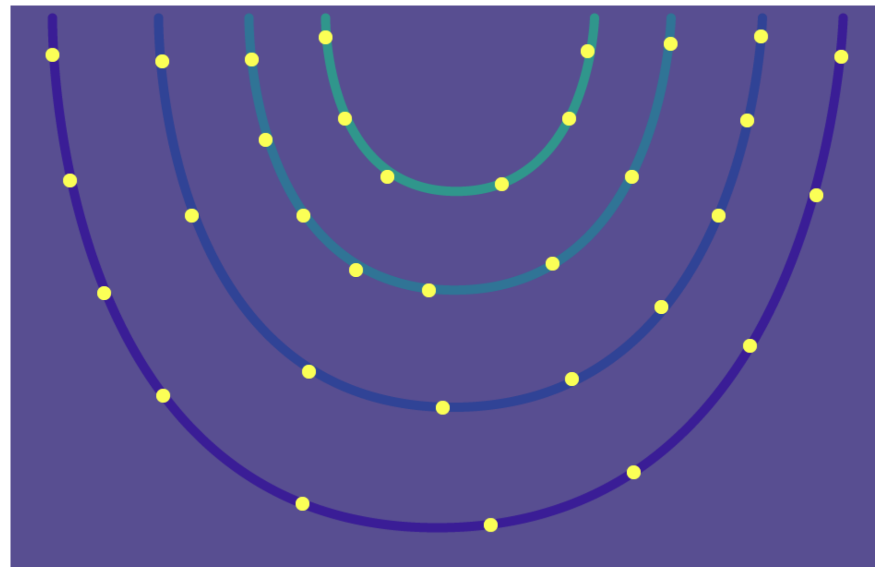
Manual Tracking of Interface: Old Method

- Static reference line
- Reference line can be placed at an angle
- Points placed at intersection of reference line and solid-liquid interface and exported as .csv



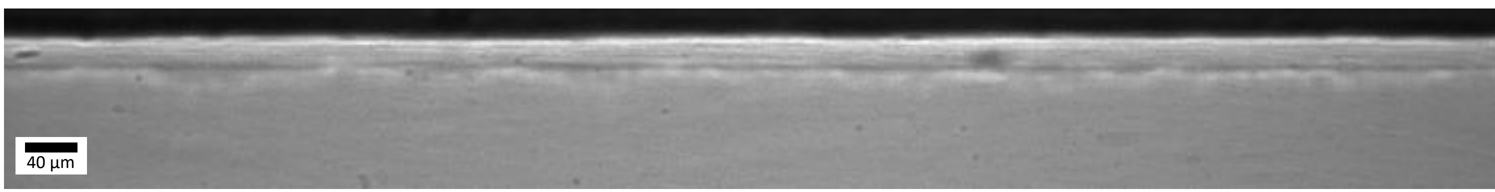
Manual Tracking of Interface: New Method

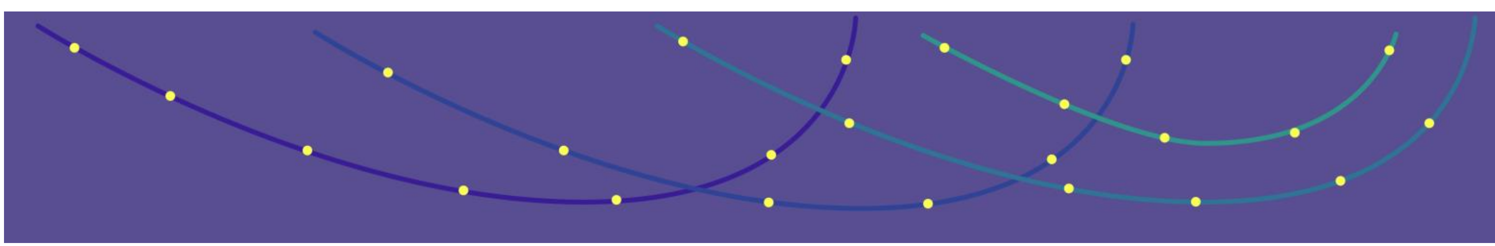
- No reference line
  - Do not need to guess useful angles/wait for further analysis
- Entire solid-liquid interface mapped and exported as .csv
  - Can be fitted mathematically
  - More options for analysis
- Can be used for spots and rasters



Manual Tracking of Interface: Line Rasters

- Ti 1023
- Laser power: 162 W (30% max)
- 5 mps raster speed
- 1.5 mm line

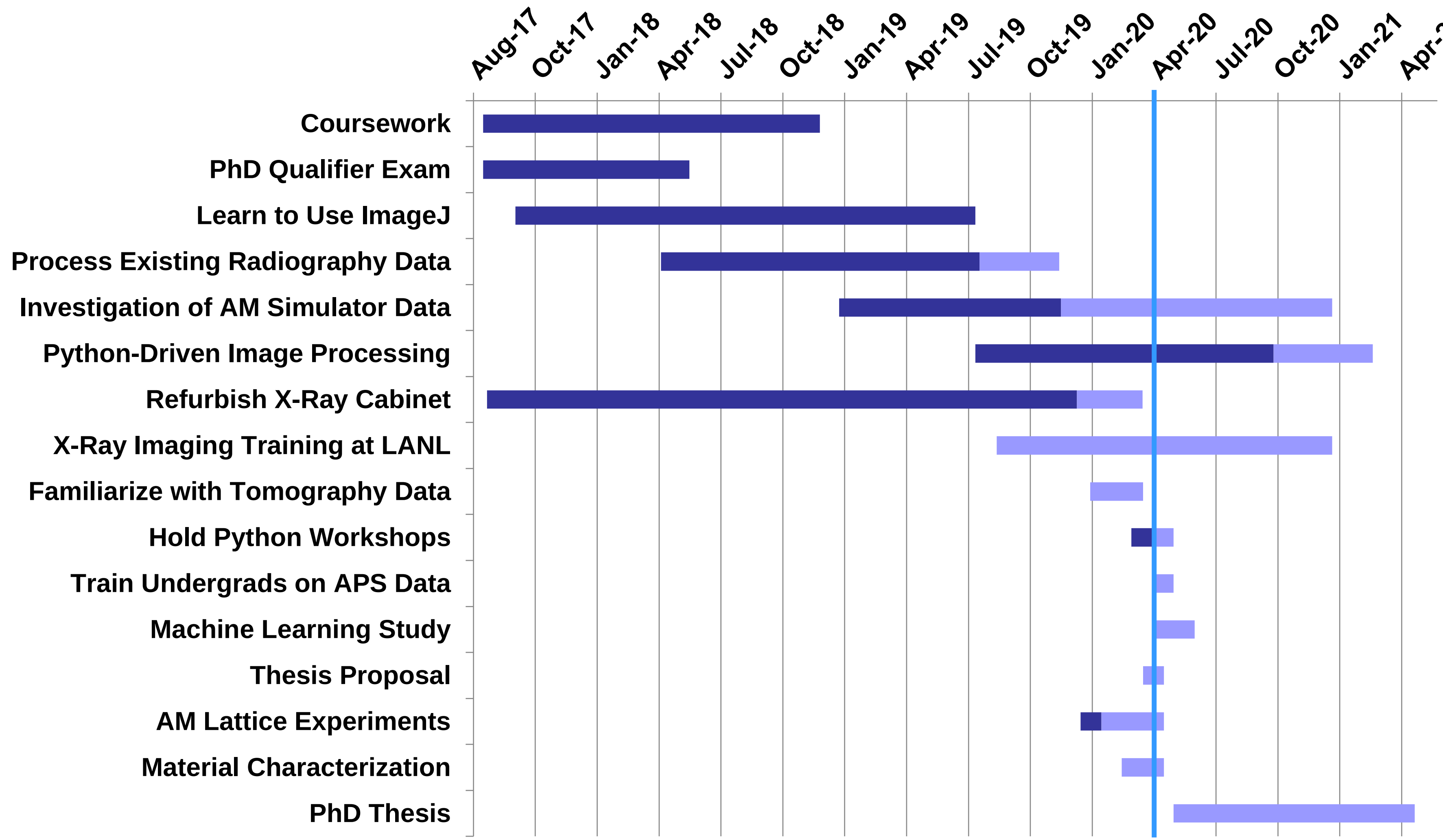




Python Workshops for CANFSA Students

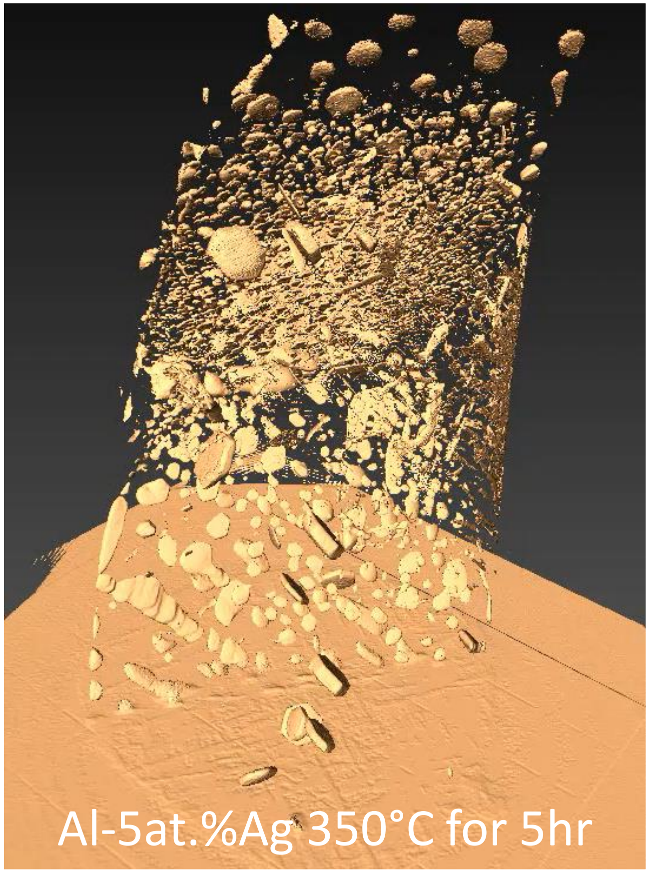
- Completed:
  - Workshop_00: Coding Basics in the Context of Python
  - Workshop_01: File Navigation/Organization and Plotting Basics
- Planned:
  - Workshop_02: Reading/Writing Files (.csv, .txt)
  - Workshop_03: Importing Data from .csv Files and Managing/Plotting Dataframes
  - Workshop_04: Image Processing
- Other:
  - Training undergrads to measure S-L interfaces

Progress


Aug-17
Oct-17
Jan-18
Apr-18
Jul-18
Oct-18
Jan-19
Apr-19
Jul-19
Oct-19
Jan-20
Apr-20
Jul-20
Oct-20
Jan-21
Apr-21
Coursework
PhD Qualifier Exam
Learn to Use ImageJ
Process Existing Radiography Data
Investigation of AM Simulator Data
Python-Driven Image Processing
Refurbish X-Ray Cabinet
X-Ray Imaging Training at LANL
Familiarize with Tomography Data
Hold Python Workshops
Train Undergrads on APS Data
Machine Learning Study
Thesis Proposal
AM Lattice Experiments
Material Characterization
PhD Thesis

Challenges & Opportunities

- Image processing to track solid-liquid interface
  - Further explore edge detection (Sobel filter)
- Train machine learning algorithm to detect interface
  - User-selected points with new macro converted to binary image as labeled training data
- 3-D reconstructions of Al alloy synchrotron tomography data
  - 2-D as pathway to 3-D
  - Explore methods to highlight differences between models (AM: reconstructions to build models)



Thank you!

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